Water quality index and heavy metal pollution index of Bailadila iron ore mine area and its peripherals

G. Jareda, P. Y. Dhekne, S. P. Mahapatra1

Abstract— **Ground water quality of Bailadila iron ore mine area & its peripheral, Dantewada district, Chhattisgarh have been studied. 20 samples were collected from hand pumps in summer season and analysed in order to find out water quality index (WQI) and heavy metal pollution index (HPI). Physio-chemical parameters such as pH, electrical conductivity (EC), turbidity, total hardness (TH), Ca+2 hardness, Mg+2 hardness, total dissolved solids (TDS), nitrate, sulphate, chloride were analyzed with standard procedure and instrumental techniques. Some heavy metals such as Al+3, Cr+6, Pb+2, Fe+2 and Zn+2 were also found out by Nova 60 spectrophotometer and Atomic Absorption Spectrophotometer (AAS). The results were compared with standards such as Indian Standard Specifications for drinking water (IS 10500), World Health Organisation (WHO) and United States Public Health Service (USPHS). From the analysis, it was found that EC, turbidity, Mg+2, sulphate, nitrate and heavy metals such as lead (Pb+2) and iron (Fe+2) are higher than the permissible limit. It was also found that only 20% of samples were soft and rest are hard water. The samples having higher iron and turbidity are of lower pH value. WQI and HPI are found as 85.143 and 85.026 respectively. It shows that ground water quality of Bailadila iron ore mine area is very poor and not safe for drinking purpose.**

Index Terms— **Physio-chemical, Spectroscopy, Water Quality Index, Heavy metal, Pollution**

I. INTRODUCTION

Of all the natural resources, water is unarguably the more essential, precious and generally available as natural resources. Those are surface water such as fresh water, river/ stream water etc and groundwater such as bore well and well water. Water has unique property due to its polarity and hydrogen bonds which mean it is able to dissolve, absorb or suspend different compounds [1]. Thus in nature, water is not pure as it acquires contaminations from its surrounding, humans and animals activity as well as from other biological activities. The quality of water is most important compared to quantity of any water supply, especially for drinking purpose purity is important. One of the most important environmental issues today is groundwater contamination and between the wide diversity of contaminates affecting water resources [2]. Groundwater pollution in various parts of the country creates a lot of terrible condition to human health. Heavy metals receive particular concern considering their strong toxicity even at low concentration. Heavy metals are elements having atomic weight between 63 to 546 and a specific gravity greater than 4.0 i.e. at least 5 times that of water. They exist in water in colloidal, particulate and dissolved phases with their occurrence in water bodies being either of natural origin such as eroded minerals within sediments, leaching of ore deposits and volcanic extruded products and due to solid waste disposal, industrial or domestic effluents. Ground water can be classified by depth. Underground water is usually present at least 30 feet deep in the earth crust and has typically been in the ground and flowing slower than shallow ground water .[3] Ground water contaminated by mine drainage often is different in chemistry from polluted surface water before chemical treatment. Polluted ground water typically has undergone a higher degree of natural neutralization than polluted surface water, because of its greater contact with carbonate minerals and slower rates of movement. Ground water contaminated by mine drainage has lower acidity and higher SO_4^{-2}, NO_3^- etc and contains metals like Iron (Fe^{+2}), Lead (Pb^{+2}), Aluminium (Al^{+3}), and suspended solids in surface mine drainage. However, in mine drainage waters, even after complete neutralization of acidity, residual pollution still exist in form of dissolved Fe, Pb, Total solids, SO_4^{-2}, NO_3^- etc. SO_4^{-2} is not normally precipitated and remains in solution following natural or artificial acid treatment. This sulphate is a good tracer or indicator of present and past mine drainage pollution. Heavy metal can cause serious health effects with various symptoms depending on the nature and quantity of the heavy metal ingested [4]. They produce their toxicity by forming complexes with protein, in which carboxylic acid (-COOH), amine ($-NH_2$), and thiol (-SH) groups are involved. These modified biological molecules lose their ability to function properly and result in the malfunction or death of the cells. When metals bind to these groups, they inactivate important enzyme systems or affect protein structure, which is linked to the catalytic properties of enzyme. This type of toxin may also cause the formation of radicals which are dangerous chemicals that cause the oxidation of biological molecules.

In present research work ground water quality parameters of Bailadila iron ore mine area and its peripherals were studied and compared with drinking water standards. Additionally WQI, HPI and water quality rating were also found to measure the suitability of samples for drinking purpose.

1.1 Study Area

Bailadila hill area located in the southern part of Chhattisgarh state [Figure 1] of India, which comes under the south Bastar, Dantewada district. It touches three states mainly Maharashtra (Western), Andhra Pradesh (North east) and Odisha (South west). Main natural resources available in the district are forest, medicinal plants, minerals, basically 75% of this region covered with forests and come under river Godavari basin. Dantewada is blessed with various mines and minerals.

G. Jareda, Department of Chemistry, National Institute of Technology Raipur 492010 India.

P. Y. Dhekne, Department of Mining Engineering, National Institute of Technology Raipur 492010 India.

S. P. Mahapatra1, Department of Chemistry, National Institute of Technology Raipur 492010 India.

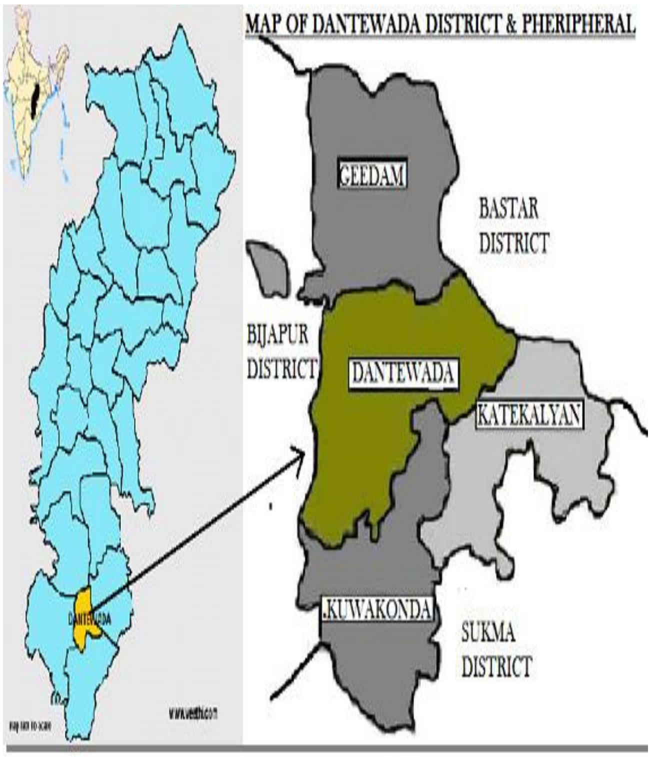

Figure 1 Location of Bailadila iron ore mine area and its peripherals: Dantewada district, Chhattisgarh, India.

Bailadila contains one of the largest deposits of Iron ore in India. The Fe content of the ore is as high grade as 64-69 % hematite, which can easily be termed as of world class quality ore. Bailadila iron ore mine extends from length of 50 km with width of about 20 km mostly along the top of hills, constitute of the richest deposit of iron in world. Different types of iron ore found in these area, such as hematite, magnetite, siderite, limonite, blue dust, etc. There are 14 deposits of iron ore with approximate quantity of 4000 lacs tonnes and approximate 780 lacs tonnes of mining wastage lower grade iron ore known as blue dust. Near about 527 villages are coming under this region. The percentage of cultivate area to total area and percentage of irrigated area to cultivate area are 82.15 sq.km and 80.21 sq.km respectively. The maximum temperature in summer rises up to 43° C between May-June whereas minimum temperature in winter drops to 10° C. The area receives heavy rains during monsoon from June to October along with the best average rain fall 1450 mm. Heavy rain fall cause depletion of minerals in water and geochemical formation of mineral rocks due to the existence of the red sandy soils and red loamy soils in wide range.

II. MATERIALS AND METHODS

Ground water samples were randomly collected from 20 sampling sites in different area of Bailadila range (Table 1). The water container used were previously washed and rinsed with 5 % nitric acid and was again later rinsed with distilled water after which they were dried and labelled before used for sample collection [5]. Before samples were collected water was allowed to run out of hand pump for 2-3 minutes to ensure the removal of unwanted residues at the mouth of opening. Water bottles were capped tightly after sample collection and the samples were then kept refrigerated under 4^{0}C before they were analyzed. The samples were collected in summer season the month of April to May. Physio-chemical parameters such as pH, Electrical conductivity & Turbidity were calculated on the spot of sampling [6]. Each groundwater sample was divided into two parts, one part for physio-chemical parameters analysis & second part for heavy metal analysis.

Table 1 Sampling Area and Sample Code.

Sampling area	Sample code	Sampling area	Sample code
Gidam	GW-01	Ganjenaar	GW-11
Dantewada	GW-02	Dugeli	GW-12
Masenaar	GW-03	Chalnar	GW-13
Dhurli	GW-04	Goipad	GW-14
Banshi Camp	GW-05	Bade Kameli	GW-15
Kusipal	GW-06	Main Market Kirandul	GW-16
Nerli	GW-07	Papachel	GW-17
Pina Bacheli	GW-08	Shyamagiri	GW-18
Bade Bacheli	GW-09	Nakulnar	GW-19
Kasipal	GW-10	Gamawada	GW-20

2.1. Sample Digestion

For the analysis of heavy metal, the removal of organic impurities from the samples was to ensured and thus prevented interference in the analysis. The samples were digested with concentrated nitric acid (10 mL of nitric acid was added to 50 mL of water in a 250 mL conical Flask). The mixture was evaporated to half of its volume on a hot plate after which it was allowed to cool and then filtered.

2.2. Sample Analysis

The analysis of water quality parameters was done using standard method. Physio-chemical parameters such as Total hardness, Ca^{+2} hardness & Mg^{+2} hardness calculated by using standard titrimetric(Complexometric) method [7]. TDS analysis was done by gravimetric method. For analysis of Al^{+3}, Cr^{+6}, Pb^{+2}, Fe^{+2}, Zn^{+2} , Cl^{-}, SO_4^{-2} , NO_3^{-} and PO_4^{-3}, Spectroquant Nova 60 photometer were used. Electrical conductivity (EC) was measured by using conductivity meter 304 Systronics and Turbidity by using Turbiquent photometer. The digested water samples were also analyzed for the presence of Al^{3+} , Cr^{6+} and Pb^{2+} using the Buck Scientific 210 VGP, AAS and the result from both were compared. The Calibration plot method was used for the analysis [8] .

III. RESULTS AND DISCUSSION

3.1. Physico-Chemical Parameters

The physico-chemical analysis was carried out and results are given in Table 2. The results of respective parameters were also discussed below.

Table 2 Physico-Chemical parameters of ground water samples collected from Bailadila iron ore mine area and it's peripheral during summer season

Sample Code	Physico-chemical Parameters									
	pH	EC	Turbidity	Total Hardness	Ca^{+2}	Mg^{+2}	TDS	SO_4^{-2}	NO_3^-	Cl^-
GW 1	8.1	412	15.1	230	82	130	547	300	63.3	145
GW 2	6.9	166	5.0	150	88	29	301	175	44.2	44
GW 3	6.8	168	4.0	91	50	26	239	197	43.6	56
GW 4	7.5	319	8.1	78	54	22	503	187	24.1	68
GW 5	7.5	284	8.7	236	186	35	361	199	40.3	138
GW 6	8.32	489	12.1	360	144	123	799	291	55.1	150
GW 7	7.7	450	4.8	152	62	29	472	187	61.3	121
GW 8	7.62	349	2.1	162	70	21	418	180	58.2	133
GW 9	8.03	458	5.0	172	98	31	615	366	65.4	147
GW 10	7.89	373	4.3	127	70	26	298	289	43.6	128
GW 11	6.21	116	2.1	123	50	29	205	196	44.1	35
GW 12	6.87	210	0.7	116	52	20	103	173	52.2	54
GW 13	7.12	493	13.5	213	133	35	612	289	58.35	158
GW 14	7.56	494	4.4	143	57	79	516	293	61.5	112
GW 15	6.77	284	5.0	88	36	27	362	98	43.5	133
GW 16	7.65	362	3.0	288	158	81	508	287	44.2	168
GW 17	7.78	300	3.6	253	138	20	251	252	41.5	41
GW 18	7.27	299	3.5	136	63	27	361	187	66.6	62
GW 19	7.98	265	3.9	183	103	73	189	190	44.9	21
GW 20	8.04	389	1.1	95	45	28	199	200	23.0	122
Note: All parameter in mg/L. except pH, Turbidity (NTU) and EC (µS/cm).										

3.1.1. pH

The observed pH values of groundwater samples collected from Bailadila iron ore mine area and its peripherals have been presented in Table 2. From the table it can be observed that pH range varies from 6.21 to 8.32. Most of the samples are existed within the minimum and maximum tolerable limits given by WHO and found slightly basic [9]. For GW 2, 3, 11, 15, pH values observed below 7.0. In natural water pH values varies due to biological activity and industrial contaminations. The decrease in pH value of water sample may be due to presence of dissolved salts such as chloride and sulphate salts of iron and magnesium. Also it may be due to acid mine drainage in the study area.

3.1.2. Electrical Conductivity (EC)

Electrical conductivity (EC) is a measure of the ability to conduct electric current. In water dissolved salts are present in their ionic forms and capable to conduct electric current. EC of groundwater samples collected from Bailadila iron ore mine area and its peripherals were given in Table 2, ranges from 116 to 494 µS/cm. From the table it can be observed that GW 1, 4, 6, 7, 8, 9, 10, 13, 14, 16, 20 samples show higher EC value may be due to presence of heavy metals and their ions, rest samples are found within the permissible limit.

3.1.3. Turbidity

Turbidity range of samples were observed from 0.7 to 15.1 (NTU) and GW 1, 4, 5, 6, 13 having higher value of turbidity may be due to presence of muddy particles in water.

Turbidity in open water may be caused by human activities that disturb land, such as construction, mining and agriculture, can lead to high sediment levels entering water bodies during rain storms due to storm water runoff. Certain industries such as quarrying, mining and coal recovery can generate very high levels of turbidity from colloidal rock particles. Higher turbidity values decreases the water acceptability with bad test [10].

3.1.4. Total Hardness (TH)

Hardness is a measure of the ability of water to cause precipitation of insoluble salts magnesium hardness (Mg^{+2}) of ground water samples collected from Bailadila iron ore mine area and its peripherals have been found and shown in Table 2. From the study it was observed that total hardness of water samples ranges from 78 to 360 mg/L. Total hardness of few samples GW 3, 4, 15, 20 are found less than 100 mg/L may be due to less availability of calcium and magnesium salts (confirmed from calcium and magnesium hardness), but higher concentration of hardness was also obtained in case of GW 1, 5, 6, 13, 16, 17 samples, which are more than permissible limit due to presence of mineral salts. In water, TH value correlates with major cations and anions like NO_3^-, HCO_3^-, Cl^-, SO_4^{-2} salts of calcium, magnesium, iron, aluminium and other heavy metals.

3.1.5. Ca^{+2} & Mg^{+2} Hardness

Ca^{+2} hardness of water samples were found in the range from 36 to 186 mg/L and Mg^{+2} hardness range varies from 21 to 130 mg/L. GW 1, 2, 5, 6, 9, 13, 16, 17, 19 are showing higher concentration of Ca^{+2} hardness and GW 1, 5,

6, 13, 14, 16, 19 are having higher concentration of Mg^{+2} hardness than permissible limit. A certain minimum amount of these elements in drinking water is desirable since their deficiency also poses at least comparable health risk. On the other hand higher amount of hardness also make the water hard with respect to its use for domestic purpose. It was also found that in study area almost all house hold water tanks deposited/precipitated with sufficient amount of hardness producing salts. These salts also may cause deposition inside body which may lead to danger.

3.1.6. Total Dissolved Solid (TDS)

TDS range of tested samples varies from 103 to 799 mg/L. GW 1, 4, 6, 9, 13, 14, 16 are having high value of TDS than permissible limit. Total dissolved solid is strongly correlated to total solid and total suspended solids. The results of early epidemiological studies suggest that even low concentrations of TDS in drinking-water may have beneficial effects, although adverse effects have been reported in two limited investigations. Water containing TDS concentrations below 500 mg/L is usually acceptable to consumers. However, the presence of high levels of TDS in water may be objectionable to consumers. Water with extremely low concentrations of TDS may also be unacceptable to consumers because of its flat, insipid and taste.

3.1.7. Sulphate (SO_4^{2-})

Sulphate range of water samples varies from 98 to 366 mg/L. GW 1, 6, 9, 10, 13, 14, 16, 17 are having higher concentration of sulphate. SO_4^{-2} ions do not disturb water test. However, there is an increasing likelihood of complaints arising from a noticeable taste as concentrations in water increase above 500 mg/L. The presence of SO_4^{-2} n drinking water may likely cause adverse effects on human health.

3.1.8. Nitrate (NO_3^-)

Nitrates occur in desirable limit essential for metabolism and healthy growth for plants and animals. Excess amount of nitrate can prove to be harmful. NO_3^- range of water samples obtained from 23 to 66.6 mg/L. GW 1, 6, 7, 8, 9, 12, 13, 14, 18 samples showing higher concentration of NO_3^- than permissible limit. Higher concentration of NO_3^- may be due to presence of dissolved minerals [11].

3.1.9. Chloride (Cl^-)

In present study chloride content of samples detected in range from 21 to 168 mg/L. The results show that all sample having within permissible limit set by WHO. Cl^-concentrations in excess of about 250 mg/L can give rise to detectable taste in water, but the threshold depends upon the associated cations.

3.2 Heavy Metals

Table 3 shows the level of the heavy metal in the studied samples. For the protection of human health, guidelines for the presence of heavy metals in water have been set by different international organisation such as WHO, USPHS and others, thus, heavy metals have maximum permissible level in water as specified by these organisation. Maximum contaminant level (MCL) in an enforceable standard set at a numerical value with an adequate margin of safety to ensure no adverse effect on human health [12]. It is the highest level of a contaminant that is allowed in a water system. The five heavy metals studied in this research namely: Al^{+3}, Cr^{+6}, $Pb^{+2,}$ Fe^{+2} and Zn^{+2} have MCL of 0.2 mg/L, 0.05 mg/L, 0.05 mg/L, 0.3 mg/L and 5 mg/L respectively.

Table 3 Concentration of heavy metals found in ground water samples collected from Bailadila iron ore mine area and it's peripheral during summer season.

Sample Code & Heavy Metal	Al^{+3}	Al^{+3} (Vs)	Cr^{+6}	Cr^{+6} (Vs)	Pb^{+2}	Pb^{+2} (Vs)	Fe^{+2}	Fe^{+2} (Vs)	Zn^{+2}	Zn^{+2} (Vs)
GW 1	0.32		**1) 0.001**		0.05		0.26		2.5	
GW 2	**0.2**		**0.005**		0.01		0.9		**2) 4.54**	
GW 3	**0.11**		**0.008**		0.02		1.2		**3) 1.44**	
GW 4	**0.13**		**0.005**		0.01		0.9		**4) 1.22**	
GW 5	**0.12**		**0.01**		0.01		0.39		**5) 5.12**	
GW 6	**0.04**		**0.001**		0.01		3.03		**6) 0.58**	
GW 7	**0.13**		**0.01**		0.05		0.2		**7) 2.98**	
GW 8	**0.11**		**0.009**		0.03		2.26		**8) 2.32**	
GW 9	**0.19**		**0.004**		0.04		0.31		**9) 3.22**	
GW 10	**0.08**	0.2	**0.002**	0.05	0.02	0.05	0.78	0.3	**10) 3.68**	5
GW 11	**0.48**		**0.005**		0		5.33		**11) 3.11**	
GW 12	**0.16**		**BDL**		0.12		1.28		**12) 4.12**	
GW 13	**0.24**		**0.008**		0		7.09		**13) 3.48**	
GW 14	**0.06**		**BDL**		0		3.66		**14) 2.84**	
GW 15	**0.03**		**0.001**		BDL		0.3		**15) 4.22**	
GW 16	**0.01**		**0.007**		0.01		5.1		**16) 4.52**	
GW 17	**0.04**		**0.005**		0.02		0.22		**17) 3.62**	
GW 18	**0.36**		**0.002**		0.02		4.02		**18) 5.02**	
GW 19	**0.02**		**BDL**		0.02		0.26		**19) 5.01**	
GW 20	**0.11**		**0.007**		BDL		6.13		**20) 2.20**	

BDL=Below Detection Level, Vs = Standard Value (Permissible limit), Concentration in mg/L.

3.2.1. Aluminium (Al^{+3})

Aluminium concetration (Al^{+3}) of groundwater samples collected from Bailadila iron ore mine area and its peripherals are given in Table 3. Aluminium is the most abundant element found in the earth's crust [11] The results obtained from analysis shows that, Al^{+3} concentration range varies from 0.01 to 0.48 mg/L. From the analysis it was found that water samples GW 1, 11, 13, 18 are contained with Al^{+3} above the specified MCL (0.2 mg/L). However average value all samples found below MCL.

3.2.2. Chromium (Cr^{+6})

Chromium concetration (Cr^{+6}) of groundwater samples collected from Bailadila iron ore mine area and its peripherals varies from 0.001 to 0.011 mg/L. The results show that concentration of Cr^{+6} in the studied region obtain well below permissible limit. It was also observed that 03 samples show Cr^{+6} concentrations below detection level.

3.2.3. Lead (Pb^{+2})

Lead (Pb^{+2}) in suspended matter and sediment comes from soil erosion in catchments with plumbo-ferrous subsoil. The possible long term effects of chronic exposure to lead (Pb^{+2}) present in drinking water are subject to considerable public concern [12,13]. Lead concetration (Pb^{+2}) of ground water samples collected from Bailadila iron ore mine area and its peripherals is given in Table 3. From the analysis it was observed that, Pb^{+2} concentration level varies from 0.001 to 0.117 mg/L. Out of 20 samples, 03 nos of samples contain high level of Lead (Pb^{+2}) concentration (> 0.05 mg/L). Out of which two samples GW 1, 7 found just near permissible limit and one sample GW 12 having maximum concentration i. e. 0.117 mg/L. Pb^{+2} has been recognised for centuries as a cumulative general metabolic poison. It is a neurotoxin and is responsible for the most common type of human lead exposure even at low levels with an increase in blood pressure as well as with reduced intelligence quotient in children and with attention disorders. In humans exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. High levels of exposure may result in toxic biochemical effects in humans which in turn cause problems in the synthesis of haemoglobin, effects on the kidneys, gastrointestinal tract, joints and reproductive system, and acute or chronic damage to the nervous system.

3.2.4. Iron (Fe^{+2})

As per WHO the permissible limit of iron (Fe^{+2}) in drinking water is 0.30 mg/L as and desirable limit can be extended up to 1.0 mg/L. In present study it was found that iron (Fe^{+2}) concentration of groundwater samples collected from Bailadila iron ore mine area and peripherals varies from 0.20 to 7.09 mg/L. Except GW 1, 7, 15, 17, 19, all samples (15 nos) are having Fe^{+2} concentration more than permissible limit. Out of which GW 3, 6, 8, 11, 12, 13, 14, 16, 18, 20 water samples are having Fe^{+2} concentrations more than 1.0 mg/L and from these 07 no of samples are having iron concentration more than 3 mg/l. which is ten times more than the permissible limits. This is mainly due to presence of iron ore in the study area and also may be due to mine drainage.

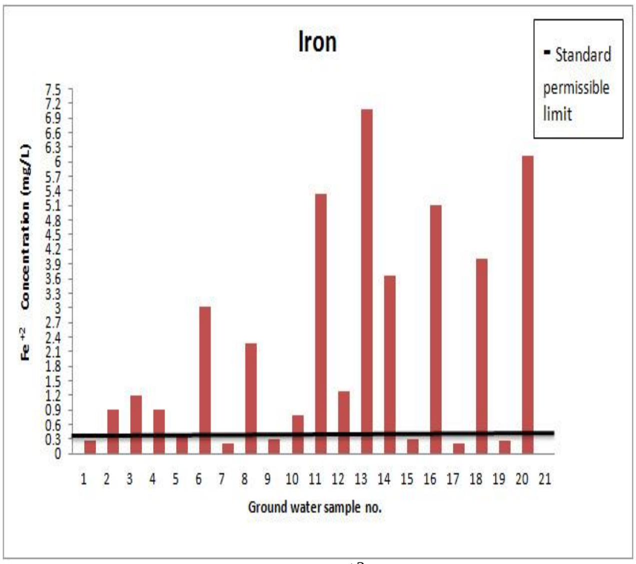

Figure 2 Iron concetration (Fe^{+2}) of groundwater samples collected from Bailadila iron ore mine area and its peripherals.

Figure 2 shows Iron concetration (Fe^{+2}) of groundwater samples collected from Bailadila iron ore mine area and its peripherals. The concentration of iron in various water samples collected near iron ore deposit contain higher level of concentration rather than location which are far apart [14]. Excess concentration of iron cause bad test along with enhance the corrosive property of water. The colour of most of the water samples colour found reddish due to highly contaminated by iron. The shortage of iron causes a disease called "anaemia" and prolonged consumption of drinking water with high concentration of iron may be lead to liver disease called as haemosiderosis [15].

3.2.5. Zinc (Zn^{+2})

The determination of heavy metal, zinc (Zn^{+2}) for all the water samples were carried out but almost all samples (except GW 5, 18, 19, just above permissible limit) contain below permissible limit 5.0 mg/l. Zn^{+2} concentration level in water samples varies from 0.58 to 5.12 mg/L. Zn^{+2} can be introduced into water naturally by erosion of minerals from rocks and soil [16]. However since zinc ores are slightly soluble in water hence found at relatively low concentrations.

3.3. Water Quality Index (WQI)

Water quality index expresses overall water quality based on several water quality parameters. It reduces the large amount of water quality data to a single numerical value and calculated from the point of view of human consumption. Water quality and its suitability for drinking purpose have been considered for calculation of water quality index [17, 18].

$$WQI = \sum W_n q_n / \sum W_n \tag{1}$$

where n= 1 to n number of parameters, W_n is unit weight of each parameter and q_n is the quality rating of each parameter. The unit weight W_n is calculated as (K/S_n), where K is proportionality constant and calculated as:

$$K = 1/[(1/S_1)+ (1/S_2) +(1/S_3)+\ldots\ldots(1/S_n)] \tag{2}$$

Where S_1, S_2, S_3,…..S_n are standard values of respective parameters.

Let there be n number of water quality parameters and quality rating (q_n) corresponding to nth term parameter is a number reflecting relative value of respective parameter in the water sample with respect to its standard permissible limits value. The quality rating qn value is calculated by the relationship.

$$q_n = 100 \, (Va - Vi) / (Vs - Vi) \quad (3)$$

Where Va is observed value (average value), Vs is standard value, Vi is ideal value, in all cases Vi = 0 except in certain parameters like pH, dissolved oxygen {Vi (pH) = 7.0 and Vi (D.O.) = 14.6}.

Using above equations WQI of Bailadila iron ore mine area ground water sample is calculated as 85.14 and tabulated in Table 4. As WQI value of the ground water sample of Bailadila iron ore mine area is approaching 100, the suitability of water for drinking purpose or human consumption is rated as very poor as per water quality rating [19]. This may be due to contamination with iron ore, mining materials, weathering of rocks, minerals and improper disposal of waste water [20, 21 & 22].

3.4. Heavy Metal Pollution Index (HPI)

The HPI, represent the total quality of water with respect to heavy metals and is developed by assigning a rating or weightage (W_n) for each heavy metal [23]. The rating system is an arbitrarily value between zero and one, reflecting the relative importance of individual quality considerations and can be defined as inversely proportional to the standard value. Generally, the critical pollution index of HPI value for drinking water is 100 [24]. The same approach is applied in present work and HPI is calculated by taking the mean concentration value of heavy metals using equations 1, 2 and 3. In present work heavy metal pollution index (HPI) for Al^{+3}, Cr^{+6}, Pb^{+2}, Fe^{+2} & Zn^{+2} metals is also calculated in Table 4 and found as 85.026. As HPI value approching 100, hence ground water samples of Bailadila iron ore mine area and peripherals are rated as very poor, unfit for drinking purpose and human consumption [25].

Table 4 Water quality index and heavy metal pollution index of ground water samples collected from Bailadila iron ore mine area and it's peripheral during summer season.

Parameter	Average Observed Value	Standard Value	Unit Weight (Wn)	Quality Rating (q_n)	$W_n q_n$
pH	7.48	6.5 – 8.5	0.002722	96.00	0.26131
EC (µS /cm)	334.00	300	0.000068	111.33	0.007570
Turbidity	5.50	5.00 (NTU)	0.00408	110.00	0.4488
TH	169.80	200	0.000102	84.90	0.00865
Ca^{+2}	86.95	75	0.0002722	115.93	0.03155
Mg^{+2}	44.50	30	0.000680	148.33	0.10086
TDS	392.90	500	0.000040	78.58	0.003143
SO_4^{-2}	226.90	200	0.000102	113.45	0.01157
NO_3^-	48.94	45	0.000453	108.75	0.04926
Cl^-	101.80	250	0.0000816	40.72	0.003322
Al^{+3}	0.147	0.2	0.10215	73.50	7.5080
Cr^{+6}	0.00529	0.05	0.4084	10.40	4.2473
Pb^{+2}	0.0250	0.05	0.4084	50.00	20.4200
Fe^{+2}	2.282	0.3	0.06806	760.66	51.7705
Zn^{+2}	3.28	5.0	0.004084	65.60	0.2679
For Water Quality Index			**∑Wn= 0.999969**		**∑ Wn*qn = 85.13973**
For Heavy Metal Pollution Index			**∑Wn= 0.99982**		**∑ Wn*qn = 85.011**
WQI = ∑ Wn qn / ∑ Wn = 85.13973/ 0.999969=85.1431					
HPI = ∑ Wn qn / ∑ Wn = 85.011/ 0.99982=85.026					

IV. CONCLUSIONS

Heavy metals such as Al^{+3}, Pb^{+2} and Fe^{+2} (mainly) concentrations found higher than permissible limit in groundwater samples of Bailadila iron ore mine area and peripherals. Most of the water samples are reddish in colour due to presence of excess iron and its salts. Higher electrical conductivity and turbidity confirm presence of iron and other metals and their salts. From the physio-chemical and heavy metal analysis, WQI was calculated and it value is found as 85.14. In addition to this HPI value of water samples is found as 85.026. As both WQI and HPI values are approaching to 100, ground water quality of Bailadila iron ore mine area and peripherals is rated as very poor. This may be because of local lithology, contamination with iron ore, weathering of rocks, minerals and anthropogenic source such as improper disposal of waste water from mining and domestic activity contamination of groundwater takes place in the studied area. This suggests a significant risk to the population due to physical and chemical pollution of water and also due to toxicity of heavy metals. Groundwater pollution would result from the same toxic overburden and mine drainage that cause surface water contamination. So groundwater of Bailadila iron ore mine area and its peripheral must be treated carefully before supplied for domestic purpose and people should be advised not to use water from hand pumps directly.

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